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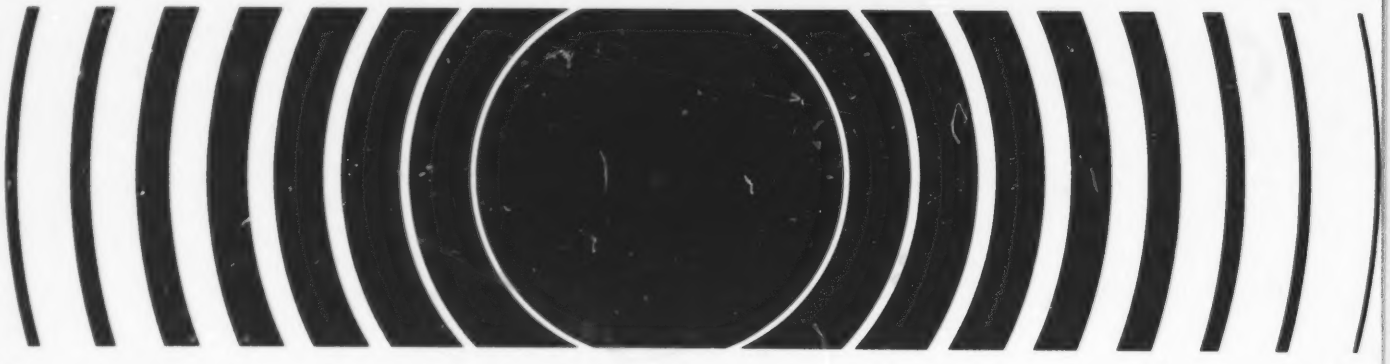

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The equilibrium ratios of measured radon concentrations and working levels in sixty-eight homes in Butte, Montana, were cataloged according to smokers and non-smokers in each home. The ratios were statistically evaluated to determine if there were differences in the average of the ratios depending on the number of smokers in the homes. The equilibrium ratio was higher in homes with smokers compared to homes with no smokers. This ratio was independent of the number of people smoking within the home.

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COMPARISON OF WORKING LEVEL RATIOS IN HOUSES OCCUPIED BY SMOKERS AND NON-SMOKERS

by

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DISCLAIMER

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PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and nonionizing radiation and to promote development of controls necessary to protect the public health and safety.

Within the Office of Radiation Programs, the Las Vegas Facility conducts in-depth field studies of various radiation sources (e.g., nuclear facilities, uranium mill tailings, and phosphate mills) to provide technical data for environmental impact assessments as well as needed information on source characteristics, environmental transport, critical pathways for population exposure, and dose model validation. The Office of Radiation Programs-Las Vegas Facility also provides, upon request, technical assistance to Western States and to other Federal agencies. The Las Vegas Facility participated in a radiation survey in Butte, Montana. The primary purpose of the survey was to intercompare various commercially-available methods of measuring radon and radon decay products; and in doing so also expand previous data relative to the sources which might elevate radon concentration in the homes. Measurements of radon concentrations and working levels are used in this report to characterize a lifestyle influence.

Readers of this report are encouraged to inform the Office of Radiation Programs-Las Vegas Facility of any omissions or errors. Comments or requests for further information are also invited.

Sheldon Meyers

Sheldon Meyers, Acting Director
Office of Radiation Programs

ABSTRACT

The equilibrium ratios of measured radon concentrations and working levels in sixty-eight homes in Butte, Montana, were cataloged according to smokers and non-smokers in each home. The ratios were statistically evaluated to determine if there were differences in the average of the ratios depending on the number of smokers in the homes. The equilibrium ratio was higher in homes with smokers compared to homes with no smokers. This ratio was independent of the number of people smoking within the home.

CONTENTS

Disclaimer ii
Preface iii
Abstract iv
List of Tables vi
List of Figures vi
Summary and Conclusions vii
Acknowledgements viii

Introduction 1
The Butte Study. 3
Design 3
Quality Assurance 4
Data Base 4
Data Selection. 4
Results and Discussion 6

References 15

LIST OF TABLES

Number		Page
1.	List of the Yearly Average of Radon Concentrations, Working Levels, and Working Levels Ratios for the Butte Study Houses	7
2.	Working Level Ratio of Continuous Measurements	11
3.	Working Level Ratio of RPISU and PERM Measurements From SILOM, ILOM, and NLOM Houses	12
4.	Working Level Ratio of Grab Sampling Measurements	13

LIST OF FIGURES

Number		Page
1.	Distributions of the Yearly Averages of Radon Concentrations, Working Levels, and the Working Level Ratios for 68 Butte, Montana, Homes	8
2.	Distributions of the Yearly Averages of the Working Level Ratios for Homes of Smokers and Non-Smokers	9

SUMMARY AND CONCLUSIONS

Measurements of radon and radon decay products were made in Butte, Montana, from October 1981 through March 1983. Of the sixty-eight homes sampled, thirty-six were occupied by persons who did not smoke. Twenty of the houses had one smoker and eleven of the houses had two smokers. No smoker information was collected for one house. Working level ratios (working level x 100 divided by pCi Rn/liter) were computed for the three types of sampling: continuous, weekly, and instantaneous samples. Statistically, all three types of measurements show significant difference between the working level ratios of residences of non-smokers and residences of smokers. The working level ratio in houses with non-smoking residents are significantly lower than the working level ratio in houses that are occupied by people who smoke. These ratios were 0.29 to 0.31 for the homes of non-smokers and 0.37 to 0.51 for homes occupied by smokers. Thus a lifestyle, such as smoking, can significantly affect the ratio of indoor radon decay products to radon.

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We are indebted to Mr. Larry Lloyd and the staff of the Montana Department of Health and Environmental Sciences for their commitment to excellence in conducting the field measurements portion of the study. We also recognize the tireless efforts of Mr. Allen Sparks, Computer Sciences Corporation, who mastered the data base and processed the data required to produce this report.

INTRODUCTION

The Butte Study arose from the investigation of the use of phosphate slag in Butte, Montana. During the fall of 1977 and the spring of 1978, the Montana Department of Health and Environmental Sciences (DHES) staff discovered that phosphate slag, produced at a nearby elemental phosphorus plant, was being used for fill, construction, and paving. Construction products were pre-stressed concrete beams and concrete blocks. Structures containing these products were identified and measured for indoor working levels (WL) during the spring of 1978. Working level measurements were made in structures which contained no phosphate slag for comparison purposes. Many of these structures exhibited working levels well above those which contained phosphate slag. Expansion of the sampling program indicated that elevated working levels were common, and other potential sources of indoor radon became suspect.

The Montana DHES requested a grant in July 1974 from the U.S. Environmental Protection Agency's Office of Radiation Programs (ORP) to expand the measurement work. The ORP awarded DHES a contract to expand the measurements and to investigate and identify the sources of radon responsible for the elevated working levels in Butte homes (L183).

The measurement of radon decay products (RDP) is both labor intensive and expensive. New radon and RDP measurement devices were appearing in the market place and offered hope of reducing the RDP measurement costs. The contract with DHES was amended and expanded to evaluate the performance of these new products. The primary purpose of the expansion of the Butte Study was to compare the ability of a variety of radon and RDP measurement devices to measure radon concentrations and RDP levels in homes. The evaluation is in progress.

Although the study was designed to compare the performance of a variety of instruments used to measure radon and radon decay products, other interesting data evolved from the study. Measurements of radon and radon progeny in houses in Butte, Montana, during the 18 months beginning October 1981 gave abundant data for statistical comparisons. The houses studied contained different numbers of smokers and the question arose as to the effect of smoking on RDP concentrations.

The following pages describe the study and show the results of smoking on the working level ratios within the houses.

THE BUTTE STUDY

DESIGN

Radon and working level measurements were conducted in sixty-eight houses. These houses were divided into three groups. The first group contained four houses and was designated Super Intensive Level of Measurements (SILOM). The second group contained 16 houses and was designated Intensive Level of Measurement (ILOM). The third group of homes was designated Normal Level of Measurement (NLOM) (Ha85) (Ny83).

Houses selected for the study were not randomly selected. The SILOM homes were selected to provide a broad range of radon and RDP concentrations. The ILOM and NLOM houses were selected from those, where possible, that had prior RDP measurements. Some houses were selected because of the willingness of the occupants to participate in the study. Even though the house selection is somewhat biased, it is believed that the selections represented a reasonable cross section of the Butte house population and radon and RDP concentrations.

SILOM houses were monitored using continuous radon gas monitors (Mo80), passive environmental radon monitors (PERM's) (Ge77), alpha track detectors (Al81), grab samples (Th71, Th72), continuous working level monitors (Mo80), and radon progeny integrating sampling units (RPISU's) (Sc74). ILOM houses received all of the above less the continuous monitors' measurements. NLOM houses were monitored using only alpha track detectors, and intermittent measurements with PERM's, RPISU's and grab samples.

QUALITY ASSURANCE

Quality assurance and control were an integral part of the study. Procedures for operating, calibrating, handling, packaging, and storing all of the measurement devices were prepared before the study began. This program has been described by Nyberg (Ny85).

DATA BASE

There are 100,875 valid measurements in the data base. Files were created for time intervals and the data were sorted into the files. Files were generated for replicate measurements, averages, and normalized averages. Several programs were written to display and to perform statistical analyses of the data. In addition, a meteorological file of hourly measurements and a file of outdoor radon measurements have been added to the data base. Information was gathered concerning the houses and occupants by questionnaire.

DATA SELECTION

Four houses had measuring devices which continuously measured radon and RDP. These four houses had PERM's and RPISU's which measured weekly radon and RDP throughout the 18 month study. Grab samples (instantaneous sampling) of radon and radon progeny were also taken weekly during the study. Sixty-four other houses were studied but continuous measurements were not included.

Initial survey questionnaires were filled out for each house studied. Data concerning the number of smokers residing in each house were collected. The data show that 36 of the houses were occupied by persons who did not smoke. Twenty of the houses had one smoker and eleven of the houses had two

smokers. The number of smokers residing in each house remained the same throughout the study. No smoking information is available for one house. Since the presence of cigarette smoke is reported (Ar73) (Co82) to affect the ratio of radon decay product and radon concentrations, correlation statistics were calculated for the number of smokers and working level ratio.

RESULTS AND DISCUSSION

An overview of the Butte data base is presented in table 1 and figures 1 and 2. Table 1 lists the annual average of radon concentrations, working levels (WL's) and working level ratios (WLR's) in Butte houses. There is a small difference in definition between the terms equilibrium ratio and working level ratio; however, for the purpose of this report, these terms shall be considered as having the same meaning and will be used interchangeably. Likewise, all radon decay product measurements cited here resulted in calculated working levels therefore these terms are also used interchangeably. The working level ratios were calculated by dividing the working level measurement for a given time period by the radon measurement for the same time period. Both measurements were made in the same room of each house at the same time.

The annual average radon concentrations are the average of two weekly PERM measurements for 52 weeks for the first twenty houses. The radon concentrations for houses 21 through 68 are the average of two simultaneous one-week PERM measurements made quarterly for one year. The annual average working level values for the first twenty houses are the average of 52 one-week RPISU measurements. Houses 21 through 68 were measured one week per quarter with RPISU's. The working level ratio is the average RPISU measurement in working levels times 100 divided by the average PERM measurement in pCi/l. Figure 1 contains frequency distributions of the annual average values as presented in table 1. The mean radon concentration for the 68 homes is approximately 6 pCi/l ranging from 2.5 to 16 pCi/l at the 68 percent confidence level. The mean working level is approximately 0.02 ranging from 0.007 to 0.06 at the 68 percent confidence level. Figure 2

TABLE 1. LIST OF THE YEARLY AVERAGES OF RADON CONCENTRATIONS, WORKING LEVELS, AND WORKING LEVEL RATIOS FOR THE BUTTE STUDY HOUSES

House	WL+	Radon (pCi/l)++	WLR+++	House	WL+	Radon (pCi/l)++	WLR+++
BS001	0.1810	71.00	0.25	BS035	0.0073	2.55	0.29
BS002	0.0730	19.60	0.37	BS036	0.0425	7.38	0.58
BS003	0.0202	11.60	0.17	BS037	0.0079	1.70	0.46
BS004	0.0100	2.83	0.35	BS038	0.0076	5.78	0.13
BS005	0.0972	31.90	0.30	BS039	0.0079	4.52	0.18
BS006	0.0814	21.60	0.38	BS040	0.0098	3.64	0.27
BS007	0.0398	9.54	0.42	BS041	0.0796	27.00	0.29
BS008	0.0416	14.70	0.28	BS042	0.0090	3.08	0.29
BS009	0.0291	11.80	0.25	BS043	0.0043	1.55	0.27
BS010	0.0564	14.30	0.39	BS044	0.0040	0.86	0.47
BS011	0.0262	8.13	0.32	BS045	0.0257	9.58	0.27
BS012	0.0388	11.40	0.34	BS046	0.0054	1.10	0.49
BS013	0.0410	20.50	0.20	BS047	0.0067	3.50	0.19
BS014	0.0853	39.90	0.21	BS048	0.0085	2.02	0.42
BS015	0.0332	11.50	0.29	BS049	0.0042	1.15	0.37
BS016	0.0688	20.90	0.33	BS050	0.0448	8.55	0.52
BS017	0.0257	8.23	0.31	BS051	0.0223	12.60	0.18
BS018	0.0297	5.67	0.52	BS052	0.0145	6.35	0.23
BS019	0.1010	31.90	0.32	BS053	0.0107	3.29	0.33
BS020	0.0792	24.10	0.33	BS054	0.0097	3.55	0.27
BS021	0.0573	19.60	0.29	BS055	0.0038	1.89	0.20
BS022	0.0112	4.55	0.25	BS056	0.0182	9.25	0.20
BS023	0.0100	5.38	0.19	BS057	0.0290	11.10	0.26
BS024	0.0199	4.63	0.43	BS058	0.0030*	0.43	0.70
BS025	0.0186	4.03	0.46	BS059	0.0109	2.55	0.43
BS026	0.0267	13.40	0.20	BS060	0.0098	2.04	0.48
BS027	0.0104	3.04	0.3	BS061	0.0287	6.94	0.41
BS028	0.0025	1.00	0.30	BS062	0.0076	1.53	0.50
BS029	0.0561	9.14	0.61	BS063	0.0051	1.53	0.33
BS030	0.0557	21.10	0.26	BS064	0.0020*	0.54	0.37
BS031	0.0024	0.63	0.38	BS065	0.0122	3.37	0.36
BS032	0.0195	9.84	0.20	BS066	0.0171	11.70	0.15
BS033	0.0303	8.62	0.35	BS067	0.0154	5.49	0.28
BS034	0.0234	4.29	0.55	BS068	0.0115	2.45	0.47

+WL = Working Level - average of 52 weekly RPISU measurements for houses BS001-BS020, average of quarterly one-week RPISU samples for houses BS021-BS068.

++Radon (pCi/l) = average of two PERM's per house for 52 weeks for houses BS001 - BS020; average of two one-week PERM measurements made quarterly for one year for houses BS021 - BS068.

+++WLR = Working Level Ratio = Average WL x 100/Average Radon (pCi/l)

* = Only grab sample average available

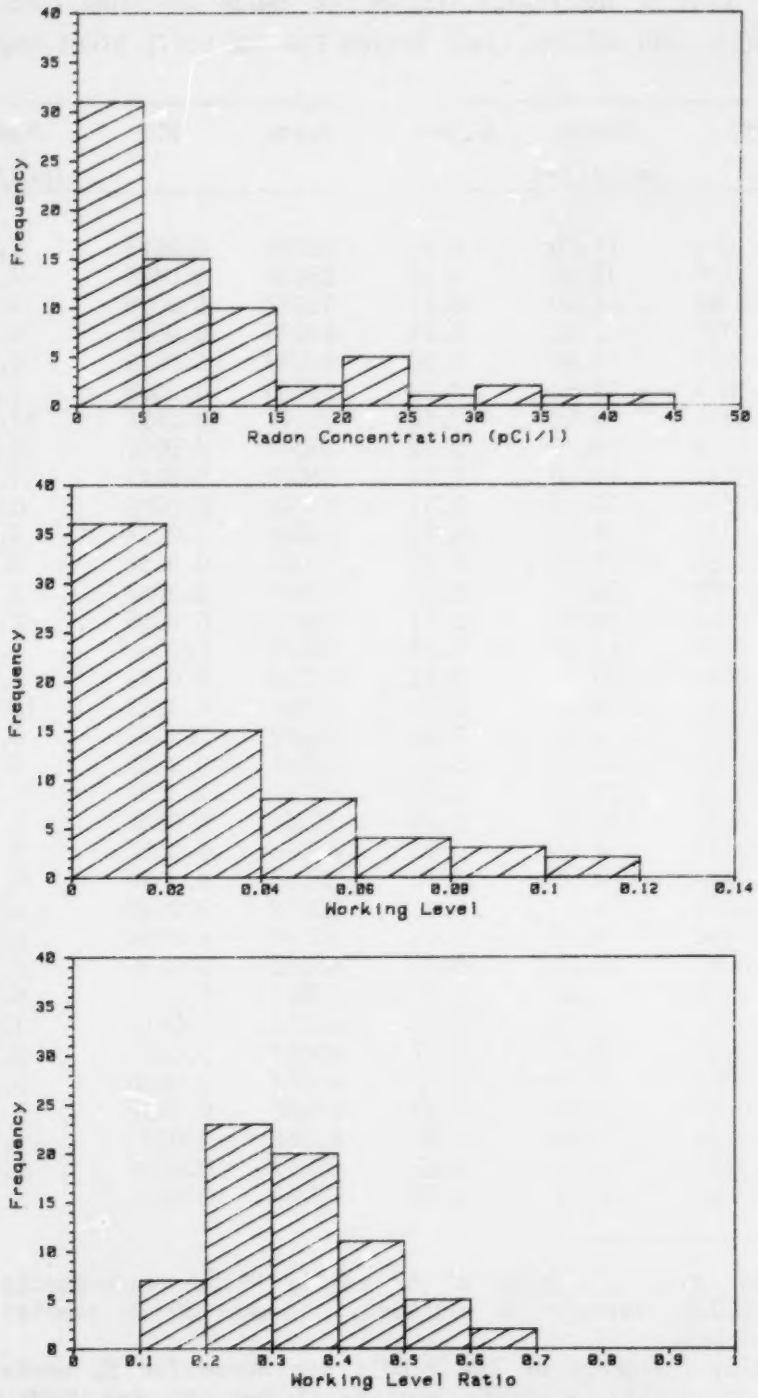

Figure 1. Distributions of the Yearly Averages of Radon Concentrations, Working Levels, and the Working Level Ratios for 68 Butte, Montana, homes.

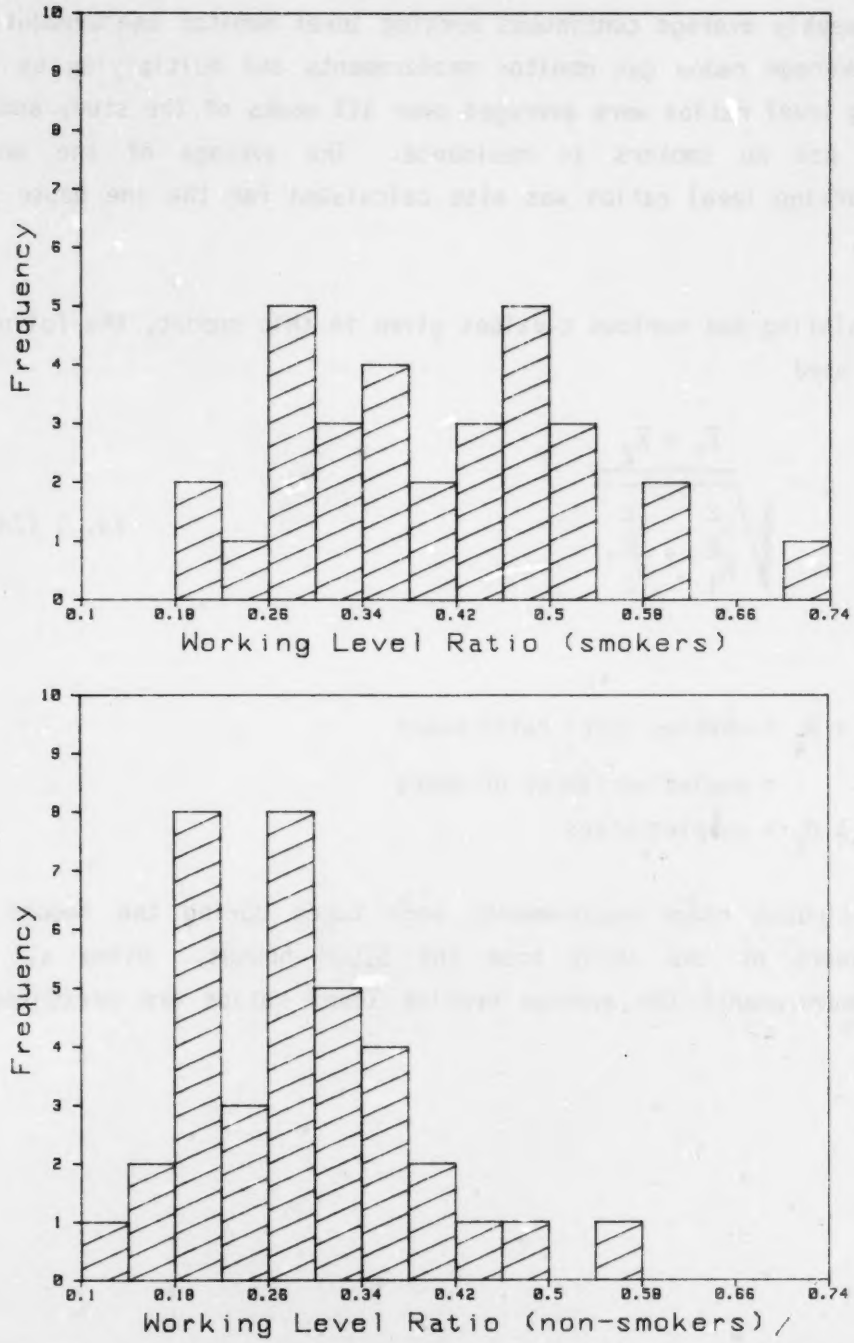

Figure 2. Distributions of the Yearly Averages of the Working Level Ratios for Homes of Smokers and Non-Smokers.

The working level ratio of continuous measuring devices was calculated by dividing weekly average continuous working level monitor measurements by the weekly average radon gas monitor measurements and multiplying by 100. These working level ratios were averaged over all weeks of the study and all houses that had no smokers in residence. The average of the weekly continuous working level ratios was also calculated for the one house that had a smoker.

In calculating the various t-values given in this report, the following equation was used

$$t = \frac{\bar{X}_1 + \bar{X}_2}{\sqrt{\frac{S_p^2}{n_1} + \frac{S_p^2}{n_2}}} \qquad \text{Eq. 1 (Za84)}$$

where $\bar{X}_1 + \bar{X}_2$ = working level ratio means

S_p^2 = pooled variances of means

n_1 & n_2 = samples sizes

The continuous radon measurements were taken during the second and third half-years of the study from the SILOM houses. Using all the continuous measurements the average working level ratios are presented in table 2.

TABLE 2. WORKING LEVEL RATIO OF CONTINUOUS MEASUREMENTS (ENTIRE STUDY)

	Mean	Standard Error	No. of Weekly Averages
Non-smokers	0.3031	0.00930	168
Smokers (1)	0.3683	0.00561	51

Using all the continuous measurement data, the presence of a smoker is indeed highly significant since $t = 6.00$ is greater than the tabulated t-value of 1.98 at $\alpha = 0.05$.

A similar comparison of the working level ratio of the PERM and RPISU data can be made. Table 3 gives the working level ratio statistics of the weekly RPISU measurements and the weekly PERM measurements. The data cover the measurements collected in the first year as well as the entire study period (one and one half years).

TABLE 3. WORKING LEVEL RATIO OF RPISU AND PERM MEASUREMENTS FROM SILOM, ILOM, AND NLOM HOUSES

	Mean	Standard Error	No. of Measurements
ONE YEAR			
Non-smokers	0.3037	0.00614	521
Smokers (1)	0.4216	0.02026	244
Smokers (2)	0.3950	0.01160	214
Smokers (1 or 2)	0.4092	0.01208	458
ENTIRE STUDY			
Non-smokers	0.2936	0.00556	641
Smokers (1)	0.4005	0.01710	297
Smokers (2)	0.3918	0.01125	225
Smokers (1 or 2)	0.3968	0.01087	522

A comparison of the means shows no significant difference between one and two smokers in a home but a significant difference between the homes of smokers and non-smokers. The t-values, in the case of one smoker versus two smokers, are t (1 year) = 1.14 and t (entire study) = 0.42; the t for smokers versus non-smokers are t (1 year) = 7.79 and t (entire study) = 8.45, respectively. The tabulated t-value at $\alpha = 0.05$ is 1.96.

Table 4 shows the mean and error of the working level ratio based on grab sampling for the first year of study and the entire study period from the SILOM, ILOM, and NLOM houses. Grab sampling and counting of radon and radon decay product measurements were completed weekly in 20 houses and quarterly in 48 houses during the study.

TABLE 4. WORKING LEVEL RATIO OF GRAB SAMPLING MEASUREMENTS

	Mean	Standard Error	No. of Measurements
ONE YEAR			
Non-smokers	0.3043	0.01264	554
Smokers (1)	0.4813	0.03354	282
Smokers (2)	0.5373	0.06297	259
Smokers (1 or 2)	0.5081	0.03484	541
ENTIRE STUDY			
Non-smokers	0.3031	0.01164	691
Smokers (1)	0.4572	0.02806	340
Smokers (2)	0.5261	0.05918	276
Smokers (1 or 2)	0.4881	0.03071	616

Grab sampling confirmed the mean comparisons of other measurements. The t-value comparing smokers are t (1 year) = 0.78 and t (entire study) = 1.05. The t-values for smoker versus non-smoker means are t (1 year) = 5.50 and t (entire study) = 8.45. The tabulated t-value is 1.96 at $\alpha = 0.05$, indicating a significant difference in the means of the working level ratio's from houses with smokers and from houses with no smokers.

An analysis of variance was made on the PERM and RPISU data for different seasons. There was a significant difference between the means of the working level ratios for each time period: winter months, full year, and entire study. The Student-Newman-Keuls multiple range test showed that the mean working level ratio was significantly lower in homes with no smokers. The test showed no difference between one or two smokers in the homes. The data shows, therefore, that the presence of a smoker or smokers may significantly affect the ratio of indoor radon decay products to radon. Such an effect has been reported previously (Co 78, Is 86, and NCRP No. 77). The mechanism suggested by these authors is that tobacco smoke provides condensation nuclei to which radon decay products may attach. As the smoke particles are small enough to remain suspended in air, the attached radon decay products are available for collection whereas if there were no smoke the radon decay products would rapidly migrate to walls, furniture, curtains, and other large objects in the indoor space.

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